Brief biographies of four chinese pioneers in the field

I. HONGFANG CHEN (1938-2017)

Hongfang Chen is a famous educator and scholar in particle physics and nuclear physics in China.

She was born in Shanghai on January 21, 1938, and graduated from the Department of Engineering Physics of Tsinghua University in 1961. In the same year she served in the Department of Modern Physics of the University of Science and Technology of China (USTC). She was a visiting scholar at the University of Wisconsin during 1979 - 1982, and at CERN during 1989 - 1991. In 1992, she was promoted to full professor. As one of the founders of the particle and nuclear physics group of USTC, she had developed the scientific research and teaching of the discipline, trained many talented students with strong academic ability and international vision, and made outstanding contributions to the development of high energy physics in China. She had earned a high reputation in the field of high energy physics. She once served as the deputy director of the department of modern physics and the executive deputy director of the class of talented young, responsible for the teaching work. She had undertaken courses such as atomic physics, topical introduction of modern physics, high energy collision physics. She had translated the book "Universal Code", and participated in the compilation of several textbooks, including Atomic Physics, Modern Physics, Atomic Physics and Quantum Mechanics, and Particle Detection Technology. She had been awarded the first-class prize of Excellent Teaching Achievements of Anhui Province (1989), the National Excellence Award of Excellent Teaching Achievements (1989), the second-class prize of Excellent Textbook of the National Education Commission (1995), the "Kun Xue Shou Wang" teaching Lifetime Achievement Award (2008), the first-class prize of Shanghai Natural Science Award (2014), and the second-class prize of National Natural Science Award (2016). She was once the executive director of the Society of High Energy Physics (China), the chair of the Institutional Board (IB) of BESIII collaboration, and the editorial board member of "Nuclear Technique". She had also served as a member of Anhui Provincial Committee of CPPCC as a public figure without party affiliation.

Hongfang Chen has been engaged in the research of experimental high-energy physics (HEP) and detection technologies, and has long been active in the frontier of particle physics and nuclear physics. From 1961 to 1965, she participated in the establishment of the magnetic spectrometer laboratory. She designed and constructed three sets of beta magnetic spectrometer (180° focused beta magnetic spectrometer, ironless double focused beta magnetic spectrometer and single lens beta magnetic spectrometer) to carry out teaching experiments. From 1974 to 1979, she participated in the development of large size multi-wire proportional chamber (MWPC). The successful construction of 50cm×150cm MWPC along with its real-time data acquisition system was awarded the Science and Technology Progress Award of the Chinese Academy of Sciences (CAS).

As a visiting scholar at the University of Wisconsin from 1979 to 1982, she participated in the E609 experiment at Fermi lab. She developed a 150cm×250cm MWPC and a delay-line multi-wire drift chamber (MWDC), and carried out performance test of the hadronic calorimeter. In 1983, she joined the L3 experiment located at CERN. Along with τ lepton physics research, she participated in the development of small-angle luminosity monitor, muon drift chamber and hadronic calorimeter. It's at this time the HEP group was established in USTC. In 1991, she led the HEP group to participate in the BES collaboration to carry out research on lepton mass measurement, ψ' physics, D physics and radiative decay of J/ψ. In 1993, she joined the CMS experiment, and established a joint research institute in cooperation with the Federal Institute of Technology in Zurich (ETH). She served as the executive deputy director, focusing on research of lead tungstate (PWO) scintillation crystal and its application in CMS electromagnetic calorimeter (EMC). During 1994 - 2000, she joined the AMS collaboration led by Samuel C.C. Ting.

In 2000, she led the USTC HEP team to join the STAR experiment at the relativistic Heavy-ion Collider (RHIC), and developed the high time-resolution time-of-flight (TOF) detector based on multi-gap resistive plate chamber (MRPC) technology. The whole barrel TOF was successfully installed into the STAR detector in 2009, which greatly improved the particle identification (PID) ability at STAR. The π/K/p PID ranges were extended to 1.6/3.0 GeV/c. Combined with the ionization energy loss (dE/dx) measurement by the time projection chamber (TPC), the identification of electrons from low to high momentum intervals was developed. In a word, with TOF the STAR experiment can identify 99% of the charged particles in the mid-rapidity region. The experimental study of the quark-gluon plasma STAR-TOF has played an key role in the study of quark-gluon plasma (QGP) and the discovery of the heaviest antimatter particle -- antihelium 4. These work won her the first-class prize of Shanghai Natural Science Award in 2014, and the second-class prize of National Natural Science Award in 2016.

Figure 1: Professor Hongfang Chen in a discussion.

In addition, she also led the USTC HEP group to participate in some other high energy physics experiments, including Belle collaboration, BESIII collaboration, CBM collaboration, etc. She has made outstanding contributions to the international frontier of particle physics and nuclear physics.

Hongfang Chen, as one of the main founders of the earliest high energy physics laboratory at USTC, has promoted USTC the most important training base for talented young people in the particle physics and nuclear physics community, and has contributed significantly in the vigorous development of the particle physics and nuclear physics research in China. She was also enthusiastic about her education career, and enjoyed a high reputation among faculties and students for her integrity, prestige and serious attitude on science. For sixty years, she took the cultivation of outstanding talents as her lifelong goal, and made outstanding contributions to the development of science and education in China.

II. LIANSHOU LIU (1932-2009)

Lianshou Liu was a distinguished Chinese Physicist, Educator, Founder of the Institute of Particle Physics at Central China Normal University, a pioneer of Chinese research on theoretical and experimental relativistic heavy ion collisions, a leader of the Chinese physics community. He served as vice chairman of the National Society of High Energy Physics, vice chairman of the Hubei Physics Society and the Wuhan Physics Society, and an awardee of National Distinguished Teacher.

Lianshou Liu was born in Wuhan, Hubei Province, in 1932. He entered Huazhong University, the predecessor of Central China Normal University (CCNU), in 1948 and graduated in 1952. As a reserve student, from 1956 to 1958, he went to the former Soviet Union, where he studied under the tutorship of the famous theoretical physicist E.M. Lifshitz. He systematically studied the series of books of Landau and Lifshiftz theoretical physics, which laid a solid foundation for his scientific career. In 1963, he was admitted to Peking University as a postgraduate student and carried out particle physics research under the guidance of Ning Hu. He participated in the research of "straton model." He proposed the covariant field theory method of the hadron structure model, which provides a computational framework for the "straton model."

In 1978, Lianshou Liu set up a research group of elementary particle theory at CCNU and began to recruit the first postgraduate student. The Institute of Particle Physics (IOPP) was founded in 1985 and he served as the director of IOPP till 2001. He made great efforts to open the channels of international cooperation and signed agreements with experts and professors from Germany, Sweden, the Netherlands, the United States and other countries for cooperative research and joint graduate student training. He led the IOPP to officially participate in the international experimental collaboration groups EMU01, ALICE (CERN, Switzerland) and STAR (BNL, US), and participated in the research work of the international experiment NA22 through international cooperation. He chaired the International Conference on Multiparticle Dynamics (ISMD) in China in 1991 and 2001. During 1983 - 2001, he hosted five international symposiums on both theory and experiments of relativistic heavy ion collisions in Wuhan. Within a short period of time, he built the institute into a research center of high energy physics and nuclear physics with certain influence at home and abroad.

In 1982, Lianshou Liu was invited by Ta-chung Meng to Berlin to cooperate in the research on the hadron-hadron collision data in the center-of-mass energy between 540 - 630 GeV from the CERN super anti-proton collider. The "Three Fireball model" had been proposed by them and successfully explained the complex phenomena found at CERN, which was widely referred to as the "Liu-Meng" model. The characteristic of the three-fireball model is that it does not investigate the dynamic process of particle generation and fragmentation, but focuses on the fact that the energy of the final particle generation in the central region and the fragmentation region comes from the kinetic energy of the two incident hadrons. Starting from this, assuming the random distribution of energy, the multiple number distribution of the three systems (the three "fireballs") is immediately obtained. Many difficult physical phenomena can naturally be qualitatively understood using the idea of the three-fireball model.

In 1980s, the large local fluctuations in phase space had been discovered in high-energy collisions, which led to the recognition that dynamic fluctuations may exist in high-energy collisions. A. Bialas and R. Peschanski proved that the statistical fluctuation could be eliminated by using the factorial moment, and the probability moment determined by the nonlinear dynamic fluctuation was obtained. The abnormal scaling property of the factorial moment can be predicted. Experimental studies of high dimensional factorial moments show that for hadron-hadron collisions, the abnormal scaling behavior expected from nonlinear dynamical fluctuations is not observed. This makes it difficult to study the dynamic fluctuations generated by high-energy collisions with multiple particles. Since the phase space of the final state in hadron-hadron collisions is highly anisotropic, the fractal should also be anisotropic if there are nonlinear dynamic fluctuations. According to this idea, Lianshou Liu and Yuanfang Wu constructed a random cascade model of anisotropy and proved that the expected abnormal scaling behavior could only be obtained by correct self-affine fractal analysis of the probability moment generated by this model. By analyzing the anisotropic dynamic fluctuations of π+p and K+p collisions at 250 GeV from NA22 experiment, according to the measured indices, the original upturned three-dimensional factorial moment-segment number double logarithm graph is turned into a straight line to observe the abnormal scaling law of nonlinear dynamic fluctuations. The data analysis results of the NA27 experimental group also support the self-affine fractal theory.

In 1983, Lianshou Liu hosted the first "Workshop on Relativistic Heavy Ion Collisions and

Quark Matter" in Wuhan, and invited L. McLerran from the United States to give a series of lectures. These lectures sowed the seeds for flourishing activities of relativistic heavy ion physics at the Institute. In the 1990s, using the cooperative research agreement, several young researchers visited the University of Regensburg successively to carry out research on the physics of relativistic heavy ion collisions. By cooperation with Xin-Nian Wang, jet physics has become an important research area at the institute. The physics of quark matter gradually became an important research direction of the Institute.

On the other hand, Ta-chung Meng strongly suggested that the institute carry out experimental research on high-energy nuclear emulsion. With Meng's help, Lianshou Liu contacted with I. Otterlund of Lund University. Through the joint efforts of Xu Cai and Daicui Zhou, a high-energy nuclear emulsion laboratory was set up in the institute, and the institute joined the EMU01 collaboration. In 1992, Lianshou Liu met J. Schukraft, then the spokesperson of the ALICE experiment, in Beijing at a LHC physics workshop. During the workshop, Lianshou Liu and J. Schukraft negotiated and reached an agreement that CCNU would participate in the LHC-ALICE experiment collaboration, which led the institute to shift from the nuclear emulsion experiment to the large heavy ion collision experiment. The Relativistic Heavy Ion Collider (RHIC) was completed in 2000. At the beginning of the new century, RHIC experiment is the mainstream of international relativistic heavy ion physics research. In 1999, Lianshou Liu invited T. Hallman, then the deputy spokesperson of the STAR collaboration to Wuhan to attend a workshop on "Relativistic Heavy Ion Collisions and the Physics of Quark Matter." During discussions at the meeting, Hallman suggested that the institute participate in the construction of the TOFp detector for the RHIC-STAR experiment. CCNU invested 700,000 yuan RMB for TOFp project, which made the university the first in joining the STAR collaboration in China. Later, Lianshou Liu invited Huanzhong Huang, Fuqiang Wang and Nu Xu as distinguished professors at CCNU, jointly training doctoral students. With the help of these Chinese American scholars, the collective motion and QCD phase structure study gradually became important research areas of the institute.

By now, the sQGP has been discovered at both RHIC and LHC. According to the finite temperature lattice QCD theory, the transition mode from hadron phase to quark-gluon plasma under the condition of high temperature and low baryon chemical potential is a smooth transition, but the microscopic mechanism of this smooth transition is still unclear.

Based on the image of the public concept of quark, Lianshou Liu put forward a basic hypothesis: there are two kinds of aggregation of hadrons: “gas type” and “molecular type.” The formation of grape-like QGP through the molecular aggregation of hadrons is a possible way to smooth the transition from hadronic matter to quark matter without violating color confinement. Lianshou Liu guided graduate students to successfully apply his idea to the calculations for QGP phase transition. At that time, both experimental and theoretical calculations support that QGP is a strongly coupled fluid. In order to verify the molecular aggregation images, he guided students to study the liquid properties of the QGP obtained from the molecular aggregation images, and found that the obtained QGP did have liquid behavior.

Lianshou Liu was not only a scientific master, but also a respectable teacher. He often said that undergraduate education was very important in order to lay a solid foundation for future scientific research. He devoted a lot of energy to “guiding” undergraduates. Since the resumption of university enrollment in China in 1978, Lianshou Liu had taught almost all the basic physics courses for undergraduates and his lecture notes had often been used as guidance for other instructors in the physics department. He focused on teaching students in accordance with their aptitude, conducted group discussions, and provided individual guidance to select undergraduates in the way he taught graduate students. Since the sophomore year, he had organized extracurricular discussion classes, helped those outstanding students make personal study plans, and regularly provided individual counseling. In this way, a number of top students had grown rapidly. Lianshou Liu devoted his life-long energy and wisdom to the cause of education and science which he loved. He trained a large number of physics talents and won the honorary title of “National Distinguished Teacher”.

Lianshou Liu passed away in Wuhan in December 2009 at the age of 77. We will always remember him as our teacher.

Figure 2: Professor Lianshou Liu in his office.

III. RU-KENG SU (1938-2022)

Born on 27 May 1938, Ru-Keng Su was a native of Shunde, a prosperous town close to the Pearl (Zhujiang) River delta in the Guangdong Province of China. Though he rarely talked about his childhood, it can be inferred that he was born into a well-off family, as he suffered during the Cultural Revolution due to his parentage. This explains the excellent education he received and his exquisite taste in literature and classical Chinese poems. At eighteen, he was admitted to Peking University, the top university in China, to study Physics. Subsequently, he left the southern border of China and traveled to the capital in the far north. The journey was uneasy for him at that time, which took several days. He told us more than once very vividly how he took the boat to cross the Yangtze river at Wuhan when the famous bridge crossing the river had not been built yet and experienced distinct folk customs in Central China.

Though harassed by continual political movements and limited food rationing during that special period, Ru-Keng Su won top-notch scores in his undergraduate studies, despite the disturbance of coercive collective labor on farmland in the daytime and volunteer work at night. Specially, Ru-Keng Su had been working extensively to assist Zhuxi Wang in composing a booklet of Concise 10-digit Logarithmic Tables as an offering to the first-decade celebration of P. R. China. He used a rolling calculator, a state-of-the-art facility in China at the time, while Zhuxi Wang double-checked his results using two abacuses. His talents were recognized, and when he graduated in 1960, he was chosen to work at Fudan University, a prestigious university in Shanghai. Since then, he started his life in Shanghai and contributed all his passion to teaching and research in the Department of Physics at Fudan University for more than half-century. He told us that on his first night in Shanghai, he wandered alone in the stadium on a bright mid-autumn night, starving and pondering about his possible future at Fudan.

Ru-Keng Su felt fortunate that he was assigned to the division of theoretical physics, where he joined the research group of senior professor Shixun Zhou. Ru-Keng Su enthusiastically plucked himself into heavy teaching and research tasks. Shixun Zhou composed a concise textbook on quantum mechanics, which became popular in numerous Chinese universities in the 1960s. This inspired Ru-Keng Su to enrich the contents, notably including more modern progress, which, in turn, gave birth to his renowned "Quantum Mechanics", which has become one of the most widely adopted textbooks in China. Even during the tough period of the Culture Revolution, Su still managed to be active in research for as long as possible, which brought him trouble and punishment. Nevertheless, his optimism allowed him to be determined in his research and to pursue a valuable life, even if he was persecuted and forced to take on unpleasant chores. After the 70s, his effort was rewarded, demonstrated by the burst of publications. He was promoted to associate professor in 1982, then to full professor in 1987, owing to his distinctive achievements in teaching and research. Since 1987, Ru-Keng Su has started to serve as a Ph.D. supervisor.

Encouraged by Chen-Ning Yang, Fudan University established a local research team on nuclear physics. The team was led by Fujia Yang, whose members include, among others, Chaohao Gu and Daqian Li. As an active team member, Ru-Keng Su's expertise and devotion were highly appreciated. Subsequently, he was invited by Chen-Ning Yang and visited the nuclear physics research group at Stony Brook, New York University, three times between 1984 and 1990. During his stay in the United States, Ru-Keng Su also visited the Institute of Nuclear Physics at the University of Washington in Seattle in 1985, where he collaborated with E.M. Henley. Besides, he visited the Department of Physics and Astronomy, University of Kentucky, from September 1989 to February 1990. Ru-Keng Su loved to tell the following story, especially to those heading for the States to pursue their studies. Once, he had to transfer in Chicago on a journey from Seattle to New York. Having heard of the violent crimes in the city, he was pretty worried about being robbed of his hard-earned salary carrying with himself. Taking advice from some Chinese fellows, he decided to wear a pair of sunglasses and a black overcoat with his hands stuck in the pockets, forming the shape of a gun. Having camouflaged himself in such an over-the-top stereotype of the local Chinese gangster and strode defiantly through the crowd in public, Ru-Keng Su arrived at his destination safely and happily, with himself and the cash intact.

In the 1990s, he worked at the City University of Hong Kong for a couple of years, where he made some good friends, including Jiju Xiao, who used Ru-Keng Su's "Quantum Mechanics" as a textbook in his lessons. It was the first Chinese physics textbook adopted in the university, extending its readership beyond Mainland China. At the beginning of the 1990s, he was invited by Tsung-Dao Lee and became a member of the advisory committee at the Chinese Center of Advanced Science and Technology. As a reward for his academic activity and support for the center, as well as a personal expression of friendship, for many years, Ru-Keng Su received greeting cards or books with Tsung-Dao Lee's paintings as New Year gifts.

Given his academic achievement, Ru-Keng Su had been elected as the vice-chairman of the Chinese Society of High Energy Physics and a member of the Senate in the Division of Mathematics and Physics of the National Natural Science Foundation of China (NSFC). Ru-Keng Su was also an active member of the Center of Theoretical Nuclear Physics in the National Laboratory of Heavy Ion Collisions in Lanzhou. In his public services, his integrity and insight were highly appreciated by most of his colleagues and peers. Many junior scientists are still grateful for the unbiased and unselfish support they received from him.

Ru-Keng Su was known for his broad interest in physics. His research spans from the subatomic realm to the far reaches of the universe. He is among the top Chinese experts in intermediate and high-energy nuclear physics. Meanwhile, he is also one of the leading physicists in general relativity and cosmology. In what follows, we briefly elaborate on a few topics demonstrating his significant contributions to the Chinese theoretical physics community.

In high-energy nuclear physics and particle physics, Ru-Keng Su explored various topics, including gauge fields, the Higg mechanism, confinement regarding soliton solutions, and vacuum and fractional charges. In nuclear physics, Ru-Keng Su's main contribution consists of several aspects. In collaboration with his student Zhi-Xin Qian, Ping Wang, Yun Zhang, Wei-Liang Qian, Li Yang, Chen Wu, and Shao-Yu Yin, studies were primarily focused on effective models for nuclear and quark matter. They have explored topics such as Coulomb instability, the speed of sound, hadrons in medium, thermodynamics, and phase transition of hadronic matter. For instance, the liquid-gas phase transition in the hadronic matter as a two-component system was explored and found to be sensitive to the isospin degree of freedom. The hadron properties, thermodynamics, and phase transition of strange hadronic matter were investigated. In addition, studies were performed for systems of quark degree of freedom to scrutinize the thermodynamics of normal and strange quark matter. The stability conditions for strangelet and strange matter were closely analyzed. Ru-Keng Su has made noticeable contributions to various relevant aspects of the quasiparticle model and its applications. These studies involve the particular role of thermodynamic consistency, the generalization of the quark mass density- and temperature-dependent model, and its applications, particularly in the context of the Friedberg-Lee soliton bag. Notably, Ru-Keng Su is well-known for his significant contributions to finite-temperature field theory, embracing both real-time and imaginary-time formalisms. Among others, these studies were primarily carried out with his students Song Gao, Yi-Jun Zhang, Zhi-Xing Qian et al..

In general relativity and cosmology, research activities were carried out with doctor or master students and postdocs in his group, including Rong-Gen Cai, Bin Wang, Cheng-Gang Shao, Li-Hui Xue, Da-Ping Du, Weigang Qiu, Jian-Yong Shen, Songbai Chen, Qiyuan Pan, Shao-Yu Yin, Chang Feng, along with other collaborators. His interest in general relativity and cosmology began in the 70s. In earlier papers published in Chinese, he discussed cosmological responses, evidence of gravitational waves, cosmological background radiation, the open universe, Dirac's cosmological model, and large-number assumption. Later, his studies embarked on topics about black holes, cosmology, and astrophysics, which appeared primarily in eminent international journals.

Overall, Ru-Keng Su published more than 200 academic papers in prestigious journals in physics and received three times the second prize for Scientific and Technological Development issued by the Ministry of Education, respectively, in 1988, 1992, and 1999. In 1999, he was awarded the second prize in the prestigious Natural Science Award issued by the Chinese Academy of Sciences.

Ru-Keng Su had taught at Fudan University for more than half a century. His lectures covered all major physics courses and contributed significantly to the curriculum reform in

Fudan. He also played a major role in tutoring students to prepare for CUSPEA, which contributed significantly to the excellent scores won by the students from Fudan. His peers highly acclaimed him for his humorous, passionate, and modern teaching methodology. Students overwhelmingly adored him for his profound insights and clear explanations and, for many successive years, rated him as the most popular teacher at Fudan. Over the years, tens of thousands of students have attended his lectures, while countless others have studied following his textbooks and online video records. Ru-Keng Su cultivated eleven Ph.D. and dozens of masters and supervised hundreds of undergraduate students. The Ph.D. students are Rong-Gen Cai (1995), Song Gao (1995), Yi-Jun Zhang (1997), Bin Wang (1998), Ping Wang (1999), Yun Zhang (2003), Wei-Liang Qian (2003), Weigang Qiu (2005), Jian-Yong Shen (2008), Chen Wu (2009), and Shao-Yu Yin (2010). There were also three postdoctoral fellows: Shuqian Ying (1993-1997), Cheng-Gang Shao (2004-2006), and Songbai Chen (2006-2008). These students who have benefited from Ru-Keng Su's teaching are engaged in various fields all over the world, and many of them are nowadays working at the front line of scientific research and education. Ru-Keng Su's knowledge and spirit will continue to be passed on and carried forward from generation to generation.

Note: Due to the volume limit, this is a short version of a more detailed text which will be published on arXiv: 2302.13332.

Figure 3: Professor Ru-Keng Su in a tour to Zhang-Jia-Jie.

IV. QU-BING XIE (1935-2013)

Qu-Bing Xie was born in Shanghai on August 1, 1935 (hometown Ningxiang county, Hunan province) and passed away in Jinan, Shandong province on December 1, 2013 at the age of 78 in a traffic accident.

In 1957, he graduated from the department of physics at Peking University and then joined Shandong University (SDU) in October 1957 as an assistant to Pu Wang (Paul Wang) (1902-1969), a famous nuclear physicist. He had been working at SDU for 48 years till he retired in 2005. He was promoted to associate professor in 1982, and was promoted to full professor in 1985. He was a visiting scholar at University of Oregon and University of Texas at Austin in the United States from 1980 to 1982 and was a visiting professor at Free University of Berlin from 1988 to 1989. From October to December 1991, he visited four universities including Tohoku University in Japan. From September to November 1996 he visited Lund University in Sweden. He served as the deputy chair of the department of physics from 1982 to 1986. In 1993, he was approved to be a doctoral supervisor by the

Academic Degrees Committee of the State Council of China. In 1995, he was awarded the title of "Top Professional and Technical Talents in Shandong Province." He has completed nearly 10 national research grants including grants of National Natural Science Foundation of China. He was awarded several research prizes from Shandong province and from Ministry of Education of China. He was authors or co-authors of about 60 published papers. He supervised nearly 20 graduate students, some of them have become professional researchers and even leaders in their research fields in China.

The history of SDU physics is tied up closely with Pu Wang. The department of physics of SDU (then National TsingDao University and renamed to National Shandong University in 1932) was founded by Pu Wang and Yi-Cheng Guo in 1930 after they graduated from Peking University in 1928. Pu Wang was lecturer in 1930 - 1935 and the chair of the department of physics in 1946 - 1947 before he moved to Germany to study for his Ph.D in experimental nuclear physics at University of Berlin and Royal Institute for Chemistry in 1935 - 1938. He moved to the United States in 1947 and held various research positions in several institutions before he returned to China in 1956. Pu Wang took the leading professorship in physics at SDU in 1956 and held the position until he died in 1969 of persecution in culture revolution.

The research field in nuclear and particle physics at SDU was founded and led by Pu Wang. In late 1950s, he proposed to focus on the method of photographic emulsion for nuclear reactions as the main research direction of SDU. This direction does not need big and expensive equipment and was easier and appropriate to develop for a Chinese university being short of financial resources at that time.

In 1959, Qu-Bing Xie and his colleague Feng-Zhu Zhu investigated the reaction events recorded in photographic emulsion and observed that there are many mesons, hyperons and many other unstable particles in reaction products. He was amazed by what he saw on nuclear emulsion and kept thinking about a theoretical explanation. After exploring into scientific literature, he found that this phenomenon was called multi-particle production and had been studied by Fermi and Landau by phenomenological models. After a few months of hard work, Qu-Bing Xie published a review article "A statistical theory for multi-particle production in nucleon-nucleon collisions" in the Journal of Shandong University in 1960. This was the first paper published in China in the field of multi-particle production in hadronic reactions. Throughout the study, he realized that there was still a long way to go to understand the mechanism of multi-particle production since the internal structure of nucleons and produced particles was unknown. His research along this line was interrupted by political movements in 1960s and was resumed in 1978 that marked the beginning of a new era of reform and opening-up.

When Qu-Bing Xie came back to research in 1978, it was established that quarks and gluons are constituent particles of nucleons and hadrons whose dynamics is governed by quantum chromodynamics. The quark model has been used to explain multi-particle production in hadronic reactions. He constructed a model for multi-particle production based on quarks and gluons to describe particle multiplicity in high-energy collisions of proton-proton and meson-proton and its collision energy behavior. This work was completed on May 1st of 1978 and was published in High Energy Physics and Nuclear Physics (predecessor of Chinese Physics C) in 1979. The method developed in this work was further extended to other high-energy reactions, known as the quark production rule, and is still in use today. The quark production rule can only give the number of constituent quarks and the average multiplicity of hadrons in high energy reactions. To give the relative proportion of different hadrons, it is necessary to know how these quarks combine into hadrons. To this end, Qu-Bing Xie used the quark combination model of Anisovich and Bjorken to describe the hadron production in hadron-nucleon reactions which agreed with experimental data very well. After his talk about the work on International Symposium on Multiparticle Dynamics in 1981, he submitted the work to Phys. Rev. D which was later published. After Qu-Bing Xie came back from the United States in 1983, he collaborated with Wen-Chuan Mo from the Department of Mathematics to formulate the rigorous quark combination rule for hadrons which accommodates the requirement of quantum chromodynamics (an extension of quark combination rule with a new and systematic formulation was made by Yang-Guang Yang et al. in 2020). The work was later published in High Energy Physics and Nuclear Physics in 1984. In the same year, the particle theory group and seminar were formed with the participation of E-Sheng Chen and Xi-Ming Liu as early faculty members and later joined by Zuo-Tang Liang, Qun Wang, Zong-Guo Si and Shi-Yuan Li. The group and seminar have lasted and flourished for years till today, out of which young students were trained and grew up to build up their own research interests and careers. These include Zuo-Tang Liang, Hai-Ping Fang, Xiao-Ping Lai, Qun Wang, Li-Li Tian, Zong-Guo Si, Feng-Lan Shao, Shi-Yuan Li, Yi Jin, Jun Song and Rui-Qin Wang. Some of them now become professional researchers and even leaders in their research fields.

Figure 4: Professor Qu-Bing Xie in a tour.

From the mid 1980s to the late 1990s, the quark production and combination rules were extensively used to study multi-particle production processes in electron-positron annihilation. In the 1980s, some researchers claimed that the baryon-antibaryon correlation predicted by Anisovich's quark combination model was in contradiction with experimental data. Qu-Bing Xie made qualitative analysis and quantitative calculation with the quark combination rule and proved that it was consistent with the experiment. He later reported the results on international conferences in 1987 - 1988 and had them published in international journals. The model was later called the Shandong model. Because of the systematic works in multi-particle production, he was awarded the Science and Technology Progress Prize of Shandong Province in 1992 and the same prize of the National Education Commission in 1993.

In past two decades, the main stream of multi-particle production has shifted to heavy ion collisions and quark-gluon plasma (QGP). The Shandong model has been applied to the hadronization of QGP and a lot of progress has been made in understanding the hadronization mechanism in quark matter.